Exploring STEM education through pre-service teacher conceptualisations of mathematics

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Keywords: collaborative learning, generic attributes, quantitative analysis, online learning

International Journal of Innovation in Science and Mathematics Education, 23(3), 35-46, 2015.

Abstract

STEM education is advocated as enhancing learning in the areas of Science, Technology, Engineering and Mathematics through delivering meaningful learning experiences to students. Although the benefits of integrating STEM into school curricula appear to warrant implementation, observations are that many teachers and pre-service teachers are not adopting STEM education. Opportunities to address STEM education with pre-service teachers may be stymied by the pre-service teachers' conceptualisations of how they use mathematics and how their students will use the mathematical concepts learnt in the classroom. This study examined links between pre-service teachers' perceptions of their use of mathematics in their everyday lives and their beliefs regarding the relevance of classroom mathematics to students' everyday lives. The participants (n=698) were first year Early Childhood and Primary pre-service teacher education students and they completed an instrument measuring their conceptualisations of mathematics. Pre-service teacher profiles were created based on the level of agreement indicated towards specific statements based on how mathematics was conceptualised from the data collected. Results suggest that pre-service teachers' conceptualisations of mathematics relates to their attitudes towards their use of mathematics in their everyday lives, numeracy in everyday life, and classroom mathematics. The study proposes that pre-service teachers' personal use of mathematics in decision making and the perception of the relevance of mathematics to children's everyday lives are identification factors in STEM being integrated into their teaching practice. Discussion of this research centres on the potential implications for the development of STEM experiences in pre-service teacher education.

Background

Science, technology, engineering, and mathematics are the discipline areas that traditionally comprise STEM education. The focus on STEM education within schools has been gaining significant momentum since the 1990s (Blackley & Howell, 2015). The Australian Government continues to advocate STEM as an educational priority in all levels of education. The aim is for Australia to secure its place in a changing global context, specifically to build economic competitiveness, to support high quality education and training, to maximise research potential, and to strengthen internal relations (Office of the Chief Scientist, 2014). The Australian Government recognises that science, technology, engineering and mathematics need to not only be taught as distinct content areas but also in approaches in which these areas complement each other (Office of the Chief Scientist, 2014). This means that mathematics should still be taught as a discrete subject but also integrated in meaningful and authentic ways.

In order to teach mathematics effectively and to integrate it with the other areas to meet to the STEM priorities, pre-service teachers in all phases of schooling must be prepared to teach content in a knowledgeable, inspirational and confident manner. It is evident that this is not occurring as Australia's global test performance in mathematics literacy have fallen; a lack of STEM qualified teachers and students entering these teaching disciplines; and teachers and pre-service teachers being reluctant to teach STEM education and the mathematics within this (Office of the Chief Scientist, 2014). This reported issue of teachers and pre-service teachers being reluctant to teach STEM highlights a concern that the integration of mathematics is not being done effectively.

Mathematics integration

The effective integration of mathematics into STEM education requires many considerations. Mathematics integration across curriculum areas can be achieved in different ways (Kärkkäinen, 2012) and frameworks have been developed to describe how teachers conceptualise mathematics integration. Trammel (2001) described how integrated mathematics involved organising content and teaching differently to traditional mathematics lessons. De Araujo, Jacobson, Singletary, Wilson, Lowe, and Marshal (2013) proposed that their framework addressed mathematics integration in terms of both how mathematics was integrated; between the strands of mathematics, through topics, across disciplines, or through context; and how the integration was situated temporally. An integrated approach to mathematics necessitates changes in teaching and learning opportunities.

The promotion and achievement of the integration of mathematics within STEM education is impacted by teacher beliefs, conceptualisation of mathematics, mathematical confidence, and mathematical knowledge. Beswick, Callingham, and Watson (2012) proposed that it is not just mathematical knowledge that is required for mathematics teaching – confidence with and beliefs about mathematics are also involved. Ernest (1989) considered teacher conceptualisation of mathematics - their "mathematical philosophy" – as an additional factor that would impact on the teaching and learning of mathematics in their classroom, particularly in terms of the mathematical experiences they would create for their students. Ernest (1989) connects the teacher's view of mathematics with how they believe mathematics should be taught and how they believe children learn mathematics, and it is these beliefs of the teacher, rather than the knowledge that is held, that will differentiate what is done in the classroom.

The teacher's perceptions of mathematics and their decisions regarding how they approach mathematics education can impact on student opportunities to engage with STEM. In their paper on the 21st century mathematics curriculum, Coffland and Xie (2015) discuss the impact of the teacher on the students' opportunities to develop mathematical understandings within the mathematics curricula sufficient to engage with and sustain STEM. They propose that the teacher's decisions regarding what to teach and how to teach drive the opportunities provided for students. Likewise, Blackley and Howell (2015) highlight the skill level of teachers, which they indicate is strongly linked to their pre-service preparation. These points indicate a need to investigate these factors for pre-service teachers, particularly as contrary views could result in disinclinations to incorporate experiences for their students that will enable engagement with STEM.

Pre-service teachers' conceptualisation of mathematics

Consideration of how pre-service teachers' conceptualisations of mathematics may impact on their learning during their study in education is needed. If practising teachers' conceptualisations of mathematics are influencing their practices of integration of mathematics, it seems likely that this may be the case for pre-service teachers. Pre-service teachers' conceptualisations of how they use mathematics and how their students will use the mathematical concepts to be learnt in the classroom may be influential factors that contribute to future teaching practices.

Ernest (1989) proposed three mathematical philosophies with which to categorise the conceptualisations of mathematics of teachers and pre-service teachers. These were: (1) mathematics as a revisable problem solving field; (2) mathematics as a static inter-connecting set of truths; and (3) mathematics as a collection of unrelated facts and skills (Ernest, 1989). The first conceptualisation of mathematics would most likely result in the integration of mathematics throughout the curriculum (Cooke, 2014). As shown in Figure 1, it would also most likely result in the integration of mathematics in a way that de Araujo et al. (2013) considered as focusing on real world situations and contexts (Cooke, 2014).

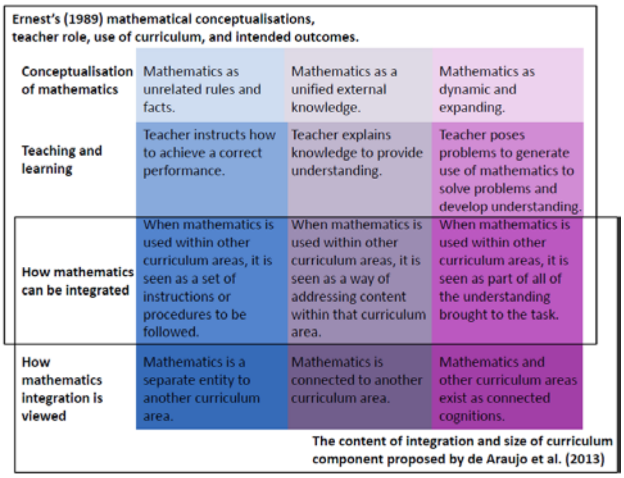

Figure 1: Cooke's (2014) diagrammatical representation of how Ernest (1989) and de Araujo et al. (2013) connect.

If pre-service teacher disposition towards mathematics may impact on their engagement with mathematics, it would be prudent to investigate how pre-service teachers conceive mathematics, their attitudes towards mathematics, and the relationships between these. This research aimed to examine links between pre-service teacher conceptualisation of mathematics by considering the level to which pre-service teachers agree with statements aligned to the conceptualisations of mathematics as a revisable problem-solving field. Specifically, their attitudes towards their use of mathematics in their everyday lives, numeracy in everyday life, and classroom mathematics.

Methodology

This study examined pre-service teachers' conceptualisations of mathematics and related mathematical perceptions. These perceptions may have developed over time and through their experiences with the world. Their experiences, in turn, are impacted by their perceptions. This interrelationship of perceptions and experiences situates this research within the constructivism ontology and the social constructionist epistemology (Crotty, 1998).

Participants

The participants (n=698) in this study were students from a compulsory first-year mathematics education unit enrolled in either the Bachelor of Education (Primary) or Bachelor of Education (Early Childhood) at an Australian university. As part of the first assessment, participants completed eight instruments to assist in their reflection on their disposition towards mathematics; however, not all eight instruments were used in this research. As this research focused on pre-service teacher conceptualisation of mathematics and attitudes towards mathematics, only data from three instruments were used: the instrument addressing conceptualisation of mathematics and the instruments investigating attitudes towards mathematics in everyday lives and attitudes towards mathematics in the classroom (Beswick, Ashman, Callingham, & McBain, 2011).

Instrument

The instrument to measure conceptualisations of mathematics comprised 20 statements. These statements addressed how mathematics is conceptualised including how it could be perceived in terms of its use and its usefulness. The categorisation of the statements was based on Ernest's (1989) pre-described three main philosophies of mathematics as pictured in Figure 2. The responses to the statements in the instrument used a 4-point Likert-style scale, where students could *strongly disagree* with the statement, *disagree* with the statement, *agree* with the statement, or *strongly agree* with the statement. All statements were worded positively, which negated the need to recode responses.

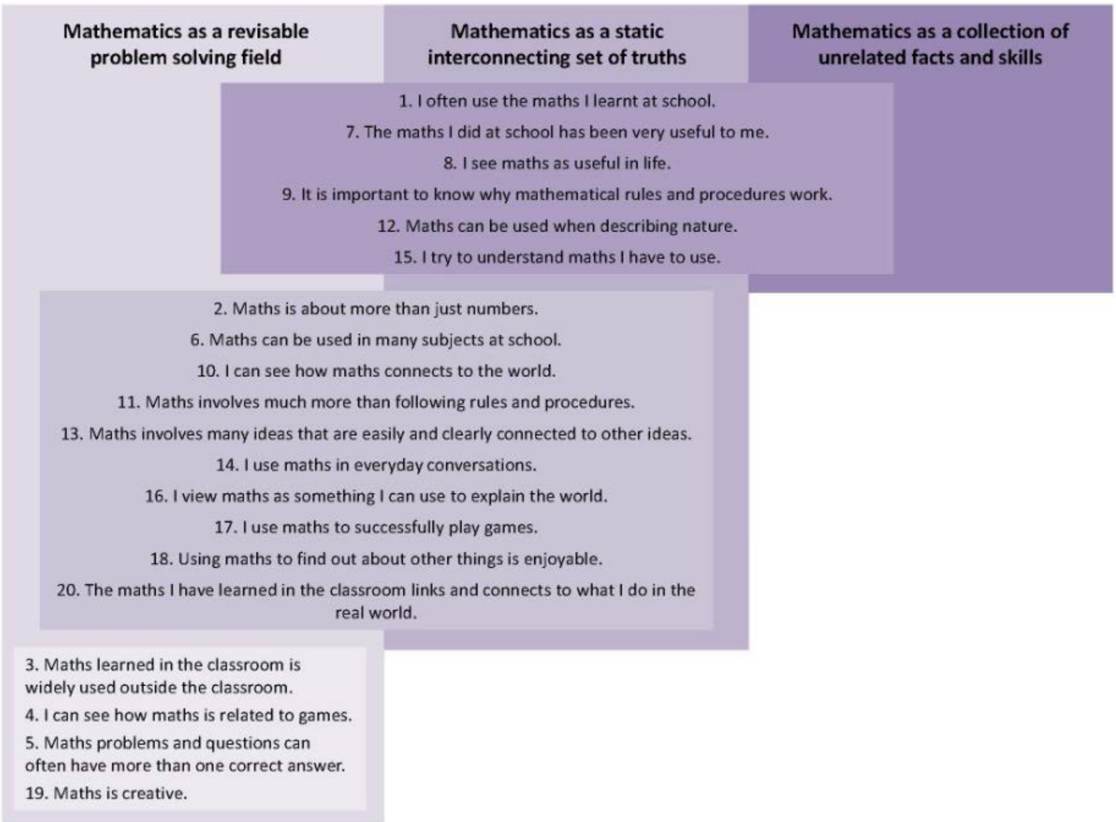

Figure 2: Cooke's (2015) alignment of the statements in the instrument with the three mathematical philosophies outlined by Ernest (1989).

There are four statements allocated to the first philosophical conceptualisation of mathematics as a revisable problem-solving field are of interest in this research, specifically:

3. Maths learned in the classroom is widely used outside the classroom.
4. I can see how maths is related to games.
5. Maths problems and questions can often have more than one correct answer.
19. Maths is creative.

Responses from five statements taken from Beswick's et al. (2011) instruments investigating attitudes towards mathematics in everyday lives and in the classroom were used to investigate pre-service teacher attitudes. These statements focused on pre-service teacher attitudes towards their use of mathematics in their everyday lives, numeracy in everyday lives, and classroom mathematics:

Items related to the use of mathematics in their everyday life:
(From the instrument Part 1 Mathematics and numeracy in everyday life)
5. I notice mathematical patterns in everyday situations.
10. I often use mathematics to make decisions and choices in everyday life.

Items related to numeracy in everyday life:
(From the instrument Part 1 Mathematics and numeracy in everyday life)
15. Numeracy is essential for effective citizenship.

Items related to children and mathematics:
(From the instrument Part 2 Mathematics in the classroom)
14. Classroom mathematics is relevant to students' everyday lives.
15. All students can learn mathematics.

Data collection and analysis

The instruments were administered through the university's Learning Management System (LMS) via a link provided to students enrolled in the unit. Participants were able to access this link for two weeks. Although eight instruments were administered there was no requirement to complete all eight in one sitting nor to complete individual instruments within a specified time limit. The responses were stored within the LMS platform. The responses to the instruments used in this research were coded as *strongly disagree*, *disagree*, *agree*, or *strongly agree*. The data file created from the responses was downloaded and the text responses were converted into numerical responses in a spreadsheet program. *Strongly disagree* responses were allocated a value of 1, *disagree* a value of 2, *agree* a value of 3, and *strongly agree* a value of 4. The final file was imported into SPSS for analysis.

Once the data were incorporated into SPSS, new codes were created to reflect the level of agreement for each of the four statements from the conceptualisation instrument. This involved recoding values of 1 (strongly disagree) and 2 (disagree) to 1 (overall disagreement with the statement) and values of 3 (agree) and 4 (strongly agree) to 2 (overall agreement with the statement). Where recoded values for all four statements were present, a new variable was created by summing the values (creating a new variable reflecting level of overall agreement, with resultant values ranging of 4, 5, 6, 7, and 8). Data from the five statements taken from Beswick's et al. (2011) attitudes towards mathematics instruments were used to create the three variables stated above, namely pre-service teacher attitudes towards the use of mathematics in their everyday lives, numeracy in everyday life, and classroom mathematics. The first and third variable, each involving responses to two statements, were created by calculating the mean of the two responses (both responses had to be present for this to occur). The second variable used the response to the relevant statement.

Two levels of analysis were conducted. The first level investigated whether agreement with more of the statements relating to conceptualising mathematics as a revisable problem-solving field was related to pre-service teacher attitudes towards the use of mathematics in their everyday lives, numeracy in everyday life, and classroom mathematics. Three Kruskal-Wallis one-way ANOVA were calculated (Allen & Bennett, 2010). If significance was indicated, a second level of analysis used the Mann-Whitney *U* test to investigate which of the rankings within the three attitudes were significantly different when considered in terms of the level of agreement with the statements relating to conceptualising mathematics as a revisable problem-solving field (Allen & Bennett, 2010).

Results

Four sets of results are reported: the first two sets of results describe the data and interpret what the frequencies indicate in terms of the focus of the research. Table 1 provides the number of participants within each variable, the mean response, and the standard deviation. As can be seen, the standard deviation is low for all four variables, indicating that responses were clustered close together. The mean for the level of agreement to mathematics as a revisable problem-solving field is high, indicating that greater numbers of students agree with more of the statements. The means for each of the measures of attitudes are in the upper half of possible responses, with attitudes showing higher agreement towards classroom mathematics and students (3.43), than towards the use of mathematics in pre-service teachers' everyday life (3.03) and numeracy in everyday life (2.88).

Table 1: Descriptive statistics for the four variables

	N	Mean	Standard Deviation
Level of agreement to mathematics as a revisable problem solving field	667	6.96	.9072
Attitudes towards the use of mathematics in their everyday lives	696	3.03	.5687
Attitudes towards numeracy in everyday life	695	2.88	.6723
Attitudes towards classroom mathematics and students	688	3.43	.4698

Figure 3 displays the distribution of responses for the four variables. The results indicate that students agree with more statements than agree with less statements, with the highest number agreeing with all but one of the statements concerning mathematics as a revisable problem-solving field. The most frequent value from the average of the two items for pre-service teachers' attitudes towards the use of mathematics in their everyday lives sits at 3.0, just above the half-way point (2.5, which is 1.5 above the minimum value of 1 and 1.5 below the maximum value of 4) and closer to the highest score possible (4.0). The scores either side are similar. The most frequent value for the response to the statement related to pre-service teacher attitudes towards numeracy in everyday life is also 3.0, but the values either side are slightly more for the response of 2.0 instead of 4.0. The most frequent value from the average of the two items for pre-service teacher attitudes towards classroom mathematics and students was slightly higher at 3.5, with a majority of values at 3.0 or higher.

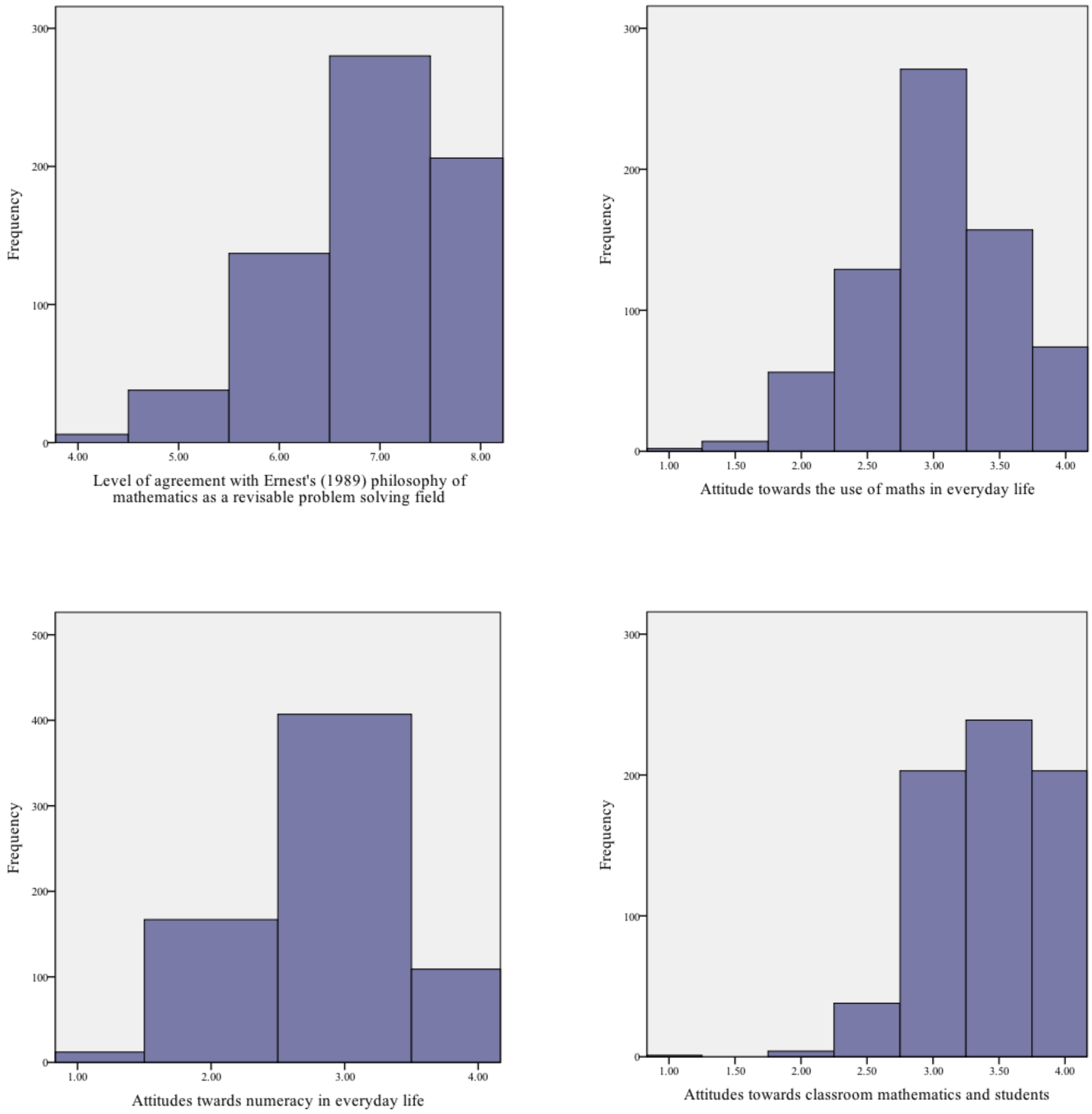

Figure 3: Distribution of responses.

The next two sets of results address the two levels of analysis that were conducted to investigate the links between pre-service teachers' conceptualisations of mathematics and their attitudes towards their use of mathematics in their everyday life, numeracy in everyday life, and the relevance of classroom mathematics to student's everyday lives. Three Kruskal-Wallis one-way ANOVA were calculated. The differences between the level of agreement to the conceptualisations of mathematics as a revisable problem-solving field and pre-service teacher attitudes towards the use of mathematics in their everyday lives was significant, H (corrected for ties) = 54.887, df = 4, N = 665, p <.000. The differences between the level of agreement to the conceptualisation of mathematics as a revisable problem-solving field and pre-service teachers' attitudes towards numeracy in everyday life was significant, H (corrected for ties) = 12.624, df = 4, N = 664, p = .013. The differences between the level of agreement to the conceptualisation of mathematics as a revisable problem-solving field and pre-service teachers' attitudes towards classroom mathematics and students was significant, H (corrected for ties) = 23.814, df = 4, N = 667, p <.000.

Table 2: Mean ranks for the three variables in terms of agreement with the conceptualisation of mathematics as a revisable problem-solving field

	Score for agreement	N	Mean rank
Attitudes towards the use of mathematics in their everyday lives	4.00	6	251.00
	5.00	38	163.80
	6.00	137	282.84
	7.00	278	358.64
	8.00	206	365.35
	Total	**665**	
Attitudes towards numeracy in everyday life	4.00	6	273.83
	5.00	38	243.16
	6.00	137	345.48
	7.00	278	339.26
	8.00	205	332.94
	Total	**664**	
Attitudes towards classroom mathematics and students	4.00	6	202.75
	5.00	38	267.01
	6.00	137	285.66
	7.00	280	352.33
	8.00	206	357.41
	Total	**667**	

As these results indicated at least two of the levels of agreement differed, Mann-Whitney *U* tests were conducted on each pair of mean ranks (Allen & Bennett, 2010). As 10 tests were conducted within each attitudes variable, a Bonferroni adjusted alpha level of .005 was used (Allen & Bennett, 2010). Table 3 provides the significant pairings and the effect size. Effect sizes annotated with ** would be interpreted as “medium” according to Cohan (1998, as cited in Allen & Bennett, 2010, p. 241).

Table 3: Significant pairings of mean ranks for the three variables in terms of agreement with the conceptualisation of mathematics as a revisable problem-solving field

Level of agreement 1			Level of agreement 2			*U*		*p*	
Level	*Mean rank*	*n*	Level	*Mean rank*	*n*	(corrected for ties)	*z*	(two tailed)	*r*
The use of mathematics in their everyday lives									
5	59.75	38	6	95.84	137	1529.50	-4.01	.000	-0.30**
5	79.95	38	7	169.24	278	2297.00	-5.84	.000	-0.33**
5	60.78	38	8	133.89	206	1568.50	-6.16	.000	-0.39**
6	176.49	137	7	223.53	278	14725.50	-3.90	.000	-0.19
6	145.19	137	8	189.83	206	10438.50	-4.28	.000	-0.23
Numeracy in everyday life									
5	66.01	38	6	94.10	137	1767.50	-3.54	.000	-0.27**
5	118.50	38	7	163.97	278	3762.00	-3.22	.001	-0.18
5	95.04	38	8	127.00	205	2870.50	-2.85	.004	-0.18
Classroom mathematics and students									
6	180.74	137	7	222.83	280	15308.00	-3.52	.000	-0.17
6	149.92	137	8	186.68	206	11086.00	-3.53	.000	-0.19

** Medium effect sizes according to Cohan (1998, as cited in Allen & Bennett, 2010, p. 241).

The four statements allocated to the first philosophical conceptualisation of mathematics as a revisable problem-solving field are of interest in this research. Specifically, that mathematics learned in the classroom is widely used outside the classroom, it can be seen how mathematics is related to games, mathematics problems and questions can often have more than one correct answer, and mathematics is creative. These four have been combined as they reflect the philosophy that mathematics is a revisable problem-solving field as outlined by Ernest (1989), and do not reflect mathematics as a static inter-connected set of truths or a collection of unrelated facts and skills. This philosophical view of mathematics is seen as more likely to result in the use of mathematics in context (Cooke, 2014).

Discussion

For STEM to be enabled or enacted, artificial silos used to organise the school curriculum need to be dismantled (Blackley & Howell, 2015). This could occur through high levels of integration, such as outlined by de Araujo et al. (2013) and Beane (1996). Using de Araujo's et al. (2013) framework, integration would focus mathematics on the real world, which is reflected in the results, with significant statistical results for attitudes towards the use of mathematics in their everyday lives and attitudes towards numeracy. Further significant findings, some with medium size effects, were shown when there was agreement with only one of the statements incorporated into the view of mathematics as a revisable problem-solving field when compared with agreement with two or more of these statements. These may indicate that creating a real world situation that uses mathematics contextually (de Araujo et al., 2013) may require a view of mathematics as a revisable problem-solving field.

All three attitudes investigated in this research could be required for experiences to reflect the dimensions Beane (1996) used when discussing curriculum integration. These are: applying knowledge, identifying connections that run through ideas, and recognition that real world problems go across the curriculum. Beane (1996) proposes that these approaches will increase the likelihood that integration will occur. The ideas have been discussed more recently. Coffland and Xie (2015) described three ways that secondary mathematics education is not sufficiently supporting student engagement with STEM: mathematics education is not connected to real life experiences, mathematics courses are not connected to each other, and mathematics education is not connected to other areas of the curriculum. Although these points are made in regards to secondary education, they are relevant to mathematics education at all levels of formal schooling.

It had been theorised that the required level of integration such as proposed by de Araujo et al. (2013), Beane (1996), Czerniak et al. (1999), and Coffland and Xie (2015) would be connected to conceptualisations of mathematics, particularly the view Ernest (1989) outlined where mathematics is a revisable problem-solving field (Cooke, 2014). This research showed that the more statements agreed with within the conceptualisation of mathematics as a revisable problem solving field (that is, Maths learned in the classroom is widely used outside the classroom; I can see how maths is related to games; Maths problems and questions can often have more than one correct answer; and, Maths is creative), the more likely pre-service teachers would endorse the attitudes that mathematics is of use in their everyday lives, numeracy is needed in everyday life, and classroom mathematics is relevant to students and all students can learn mathematics.

Pre-service teachers and teachers who do not endorse attitudes regarding the usefulness and need of mathematics in everyday life and the relevance of classroom mathematics to student lives may not make connections or integrate mathematics. The risk of not making connections within mathematics and between mathematics, other curriculum areas, and the world is that pre-service teachers, teachers, and students will not be able to sustain the mathematical disposition and understandings needed to engage in STEM. The Chief Scientist, Ian Chubb, states that there is a "cycle of disengagement that fails our teachers and students today" (2014, p. 21). Two of the suggestions to combat this are through supporting teachers and inspiring students. This would incorporate the proposed view of mathematics in terms of how it:

> Seeks to understand the world by performing symbolic reasons in and computation on abstract structures and patterns in nature. It unearths relationships among these structures, and captures certain features of the world through the processes of modelling, formal reasoning and computation. (Office of the Chief Scientist, 2014, p. 34).

An example of how these connections can be made and developed through modeling, reasoning, and computation is provided by Mulligan and English (2014). Their research demonstrated that, if given appropriate tools and scaffolding, children in early childhood (Grade 1) could make connections and integrate ideas across mathematics and within science through the use of real world contexts and investigations. Mulligan and English (2014) demonstrate one of the many ways mathematics can be of use, useful, connected, and integrated. However, to do this, it would be necessary for the teacher to be able to conceptualise mathematics as a revisable problem-solving field (Ernest, 1989), and have beliefs commensurate with mathematics as of use and needed in everyday lives (Beswick et al., 2011; Beswick et al., 2012).

Conclusion

In considering the aim for Australia to secure its place within an ever-changing global context and to build economic competitiveness, it will be necessary to support STEM education, high quality education and training (Office of the Chief Scientist, 2014). It becomes imperative that initial teacher education programs consider the integration of STEM education and pre-service teacher conceptualisations of mathematics in their programs and not just focus on mathematics skills and/or competency (Katz & Raths, 1985). Exploration of experiences that can enable pre-service teachers to revise how they see and interact with mathematics would also become crucial to initial teacher education programs, particularly if their previous mathematical experiences did not enable or encourage this (Sullivan, Mousley, & Zevenbergen, 2006). In addition, the silo curriculum and pre-service teacher education focusing on the skills, competencies, and knowledge needs to be considered (Blackley & Howell, 2015). However, these might be for naught if the pre-service teachers' conceptualisations of mathematics and their attitudes towards their use of mathematics in their everyday life, numeracy in everyday life, and the relevance of classroom mathematics to student's everyday lives are not also addressed. These issues must be considered if STEM education is to be realised.

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